Analysis of the Impact of Petroleum Prices on the State of Hawaii's Economy

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by

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Executive Summary

This report is one of a series of reports prepared as part of a request by the Secretary of Energy to evaluate the economic consequences of Hawaii's dependence on petroleum under a number of scenarios, as authorized under Section 355 in the Energy Policy Act of 2005. This particular report provides a set of analyses of the impact of petroleum prices on the state of Hawaii's economy.

Hawaii was chosen for this type of study for a number of reasons. First, it is relatively easier to model inputs and outputs of the state economy due to its relative and unique isolation from other economies, as compared to other states in the country. Second, the state is uniquely dependent on petroleum for most of its energy needs, particularly for electricity generation. Oil provides almost 90% of the total state energy needs. A significant amount of that oil is used for electricity generation; 78% of electricity needs are met through oil-burning as opposed to a national average of just 3%.

Two types of impacts were evaluated, a set of oil shock cases and a set of Energy Information Administration (EIA) scenarios. A static model was used for the price shock scenarios and a dynamic model was utilized for the EIA scenarios. Both models were developed by members of the University of Hawaii Economic Research Organization (UHERO). While many recent analyses only examine impacts associated with longer-term trends based on EIA projections, it was concluded that these relatively slow, monotonic projections did not adequately allow for the impacts that are normally seen under real world conditions. Specifically, most recent (since 1973) impacts to economies due to oil price changes have been due to sudden rises in oil prices. Thus, the analyses of these price shocks and volatility attempt to better evaluate the impacts to the state's economy.

The main dataset used for this study was the 1997 Hawaii State Input-Output (I-O) Table. This dataset was chosen because energy markets are relatively disaggregated within the table (i.e., electricity is separate from other utilities). The dataset has been updated using 2000 census data. These provide data on 131 sectors, three factor markets, and eleven agents of final demand. A social accounting matrix was assembled from these data to describe the flow of goods, services, and other economic factors through the state's economy. The purchases of intermediate inputs and primary factors (labor and capital) are also provided for each of the 131 production sectors. Since tourism is an important part of the State's economy, information on and impacts associated with the presence and expenditures of visitors to the state were also analyzed.

Supporting existing literature on oil price/macro-economic relationships, it is shown that relatively sudden oil price increases are bad for the state economy. For a doubling of oil prices, a 2.4% decline is seen in the overall Gross State Product. The Consumer Price Index increases by 1.3%, while the Visitor Price Index increases by 3.8%. On a sectoral level, three sectors are impacted to a considerable extent. With a doubling of oil prices, real output in the farming sector decreases by over 10% in real

(constant) dollars and decreases by almost 8% in nominal (current) terms. Petroleum manufacturing and electricity generation show similar results as compared to one another. In real dollars, petroleum manufacturing declines by almost 35%. Electricity generation declines by 12% in the scenario cited above. However, in nominal terms under a doubling of oil prices, petroleum manufacturing increases by 20% and electricity generation increases by 8%. These model results suggest that, while individuals will alter behavior to spend less on electricity and oil products, the net effect is to take money out of the economy for expenditures in other sectors. This is supported by projections for real household demand. These suggest that petroleum product use and electricity use decline by 47% and 21%, respectively, when oil prices are rapidly doubled.

The analyses of the EIA scenarios do not demonstrate as significant a set of impacts. The comparison of the high and low oil price trends shows some significant differences, if considered over the 20 year period contained in the projections. In constant dollars, there is a $2 billion impact on the Gross State product in 2025 of a high oil price path over a low oil price path. This aggregates to a cumulative $22 billion impact between 2006 and 2025. On a household basis, there is $2.2 billion dollars less available to households in 2025, a reduction of 2.5% of real household expenditures. While relatively small, this difference can have a more significant impact on other commercial sectors as purchasing of goods in those sectors is reduced.

In summary, increased oil prices will have a negative impact on the State economy in either a price shock situation or a longer-term increase in oil prices. Similar to findings by other researchers, increasing and volatile oil prices have a greater impact on the economy than slow and steady increases in prices. Even in examining the more modest impacts of longer-term, gradual increases in prices, the impact to the State economy, measured in constant dollars to be $70 billion in 2025, is on the order of 2.5% of the total economy. This is a sizable difference in an economy that is predicated on the increase in price of only one commodity – oil.

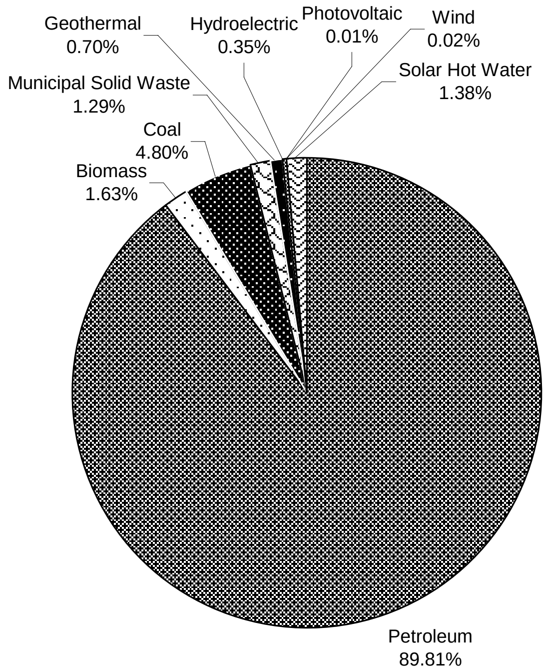
1.0 Introduction

Section 355 within the Energy Policy Act of 2005 authorizes the United States Department of Energy (DOE) to evaluate the economic impacts to the state of Hawaii as a result of changing petroleum prices. Further, language in Section 355 requires an analysis of several supply-side scenarios that may alleviate Hawaii's high dependence on petroleum: renewable resources for electricity generation and transportation, and insertion of liquefied natural gas (LNG) into the state's energy supply mix.

Based on this authorization, the DOE Offices of Electricity Delivery and Energy Security and Energy Efficiency and Renewable Energy provided funding to the University of Hawaii's Hawaii Natural Energy Institute to lead this analysis and evaluation. Some of this funding was directed through the State of Hawaii's Department of Business, Economic Development, and Tourism (DBEDT). The University of Hawaii Economic Research Organization (UHERO) conducted the analysis for this chapter.

While this analysis is focused on Hawaii, it has broader implications for energy security at the national level. Hawaii is an excellent case study because its remote geographic location and high level of oil-dependence makes it particularly vulnerable to changing oil prices. Almost 90% of Hawaii's energy needs are provided by petroleum (Figure 1).

Figure 1. State of Hawaii Primary Energy Sources 2005



Source: State of Hawaii Strategic Industries Division

Unlike the rest of the states in the United States, Hawaii uses petroleum not only as a transportation fuel but also for a very large percentage of electricity generation. In 2005, just over 80% of Hawaii's electricity was produced using petroleum fuels, including residual fuel oil, naphtha, and diesel fuel purchased from the Chevron Hawaii and Tesoro refineries on Oahu (Figures 2 and 3).

Figure 2. Petroleum Refinery Operations

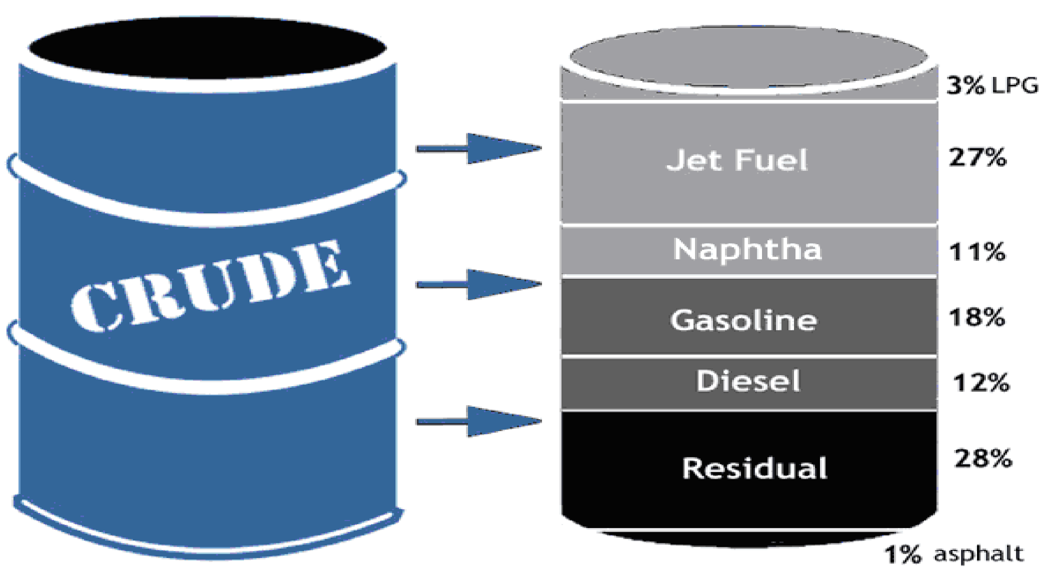
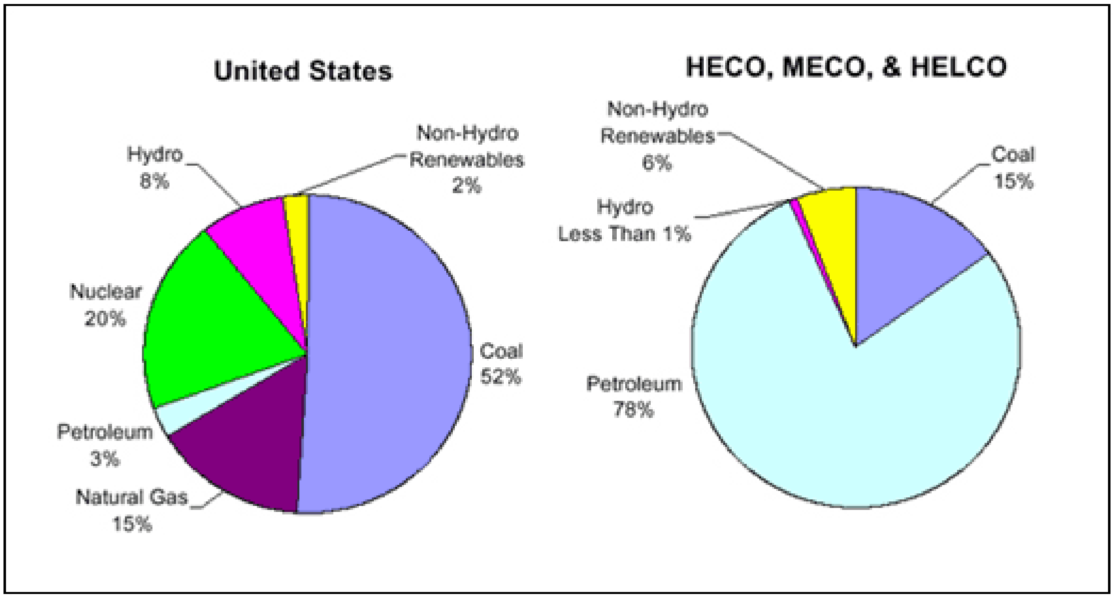


Figure 3. United States vs. Hawaii Electricity Composition



Source: Hawaiian Electric Company, www.heco.com.

Hawaii's economy is vulnerable to oil price shocks because of its geographical remoteness, tourism-defined economy, and the significant use of oil for the generation of electricity. Per direction from DOE and DBEDT, this study attempts to evaluate the oil price/macroeconomic relationship for Hawaii by: 1) analyzing sudden oil price volatility or "shocks" and 2) analyzing long-term, monotonic oil price increases over time using DOE Energy Information Administration (EIA) world oil price projections.

Because Hawaii is a unique state in many ways, computable general equilibrium (CGE) models of Hawaii's economy have been developed to reflect the linkages between industry, households, residents and government. Two models are used, one static and the other dynamic. The static model is used to assess the economic effects of sudden oil price shocks to Hawaii's economy. The price shock scenarios better typify historical changes in oil prices.

The dynamic model projects to the year 2025 under three EIA oil price predictions. The effects of oil price increases for both sets of scenarios are analyzed in terms of their effects on price levels, overall and sector level productivity, as well as resident and visitor welfare.

2.0 Oil Prices and the Macroeconomy

2.1 Historical Background

General equilibrium modeling developed out of the public finance literature and was endorsed for providing economy-wide feedbacks for questions of international trade, energy and inter-industry supply and demand, factor markets, and consumer demand (Shoven & Whalley, 1972). CGE models in particular, using the General Algebraic Modeling System (GAMS) and/or the Mathematical Programming System for General Equilibrium (MPSGE) formats, provide a tractable way of using detailed sector-level data for an economy to generate an equilibrium considering the actions of all major players (households, firms, government, and the rest of the world).

The literature on oil price increases and its link to macroeconomic performance plainly suggests a negative relationship, although the timing of the relationship and the impact of foresight and speculation is still somewhat unclear. A simple timeline analysis of oil price shocks and U.S. recessions shows the complexity of the relationship. Barsky and Kilian (2004) give an in-depth history of oil price increases and U.S. recessions. The recessions that started in November 1973 and July 1990 occurred before the oil price increase, the recessions that started in July 1981 and March 2001 occurred during the decline in oil prices after its peak, while the recession of 1980 followed an oil price increase. While the causality and relationships are on the surface unclear, it "seems difficult to maintain that the two phenomena are unrelated" (Barksy & Kilian, 117).

Hamilton (1983) was seminal in linking oil price increases to U.S. recessions in the pre-OPEC era prior to 1973 (see also Rasche and Tatom, 1981; Darby, 1982; Burbidge and Harrison, 1984; Olson, 1988; and Perron, 1989). Using econometric vector auto-regression analysis and statistical causality tests between oil price changes and real GNP, Hamilton (1983) finds that oil price shocks contributed to U.S. recessions. Oil price increases were followed by slower output growth with roughly a year lag (3-4 quarters), albeit a temporary phenomenon (6-7 quarters). Hamilton (1983) does not suggest that all recessions are oil-related, but rather that oil prices contributed to the timing, magnitude and/or duration of U.S. recessions.

There has been substantial research regarding the effect of sudden oil price shocks on other macroeconomic indicators such as inflation and wages. There is large consensus within the literature that oil price shocks are inflationary (Barsky and Kilian, 2002, 2004). Coupled with a decline in aggregate output, the inflationary nature of oil price increases leads to a period of stagflation within an economy, as evidenced by the country's economic behavior in the 1970s.

Contrary to the predictions of standard growth models that suggest output decreases when real wages increase, oil price increases are found to reduce real wages as well as output (Bohi, 1989, 1991; Keane and Prasad, 1996). Keane and Prasad (1996) find that oil price increases reduce real wages in all sectors of the U.S. economy, although the magnitude of change varies by sector. Their findings support the idea that labor and oil are net substitutes (meaning there is no income effect, only substitution effect, in their relationship) and not gross substitutes – as being gross substitutes implies that an increase in oil prices would lead to an increase in aggregate labor demand and real wages across sectors. This means that that elasticity of substitution between energy and labor is less than unity, as represented in the Hawaii CGE models employed in this study.

Hamilton (1988) takes a closer look at the reasons *why* oil price increases and subsequent relative price shifts have an aggregate impact on macroeconomic performance. He argues that a shift in relative prices, including real wages, causes labor to shift amongst sectors. These shifts are not costless. The reallocation of labor and the lag in structural adjustment can have real economic impacts.

In the same vein of explanation, Bernanke (1983) argues that firms delay capital investments (if they are viewed as being irreversible) during periods of uncertainty, including uncertainty caused by fluctuating oil prices, to see whether the change is temporary or permanent. Barsky and Kilian (2004) discuss that the empirical evidence for such a "waiting" effect is quite small, particularly in looking at car sales in the U.S. around oil price shocks.

Since the 1970s and with more data on oil price shocks over time, economists have reassessed the oil price-macroeconomy relationship. With the oil price decreases of the 1980s, there was extensive debate on the relationship between oil price increases, oil price decreases, and macroeconomic performance. Olson (1988) and Mork (1989) show that oil price increases do not necessarily have the opposite effect of oil price decreases. Olson (1988) argues that oil price decreases can have potentially negative effects on the economy because of structural adjustment costs similar to the arguments put forth by Hamilton (1988) and Bernanke (1983). Hooker (1996) demonstrates that in the post-OPEC era, there is no longer a linear relationship between oil prices and output. Hamilton (1996) argues that his initial assumption of a linear relationship between oil prices and macroeconomic indicators did not contradict his results using the pre-1973 dataset because there simply were few cases of oil price decreases. He concedes that such an assumption is no longer valid in the post-1973 analysis because fluctuating prices have become a more common phenomenon. He suggests that individual oil price increases since 1986 were corrections to earlier oil price declines and thus he normalizes the dataset to reflect net oil price increases. With this specification, he finds the relationship between oil price shocks and U.S. recessions further strengthened.

Extensions of the literature include analyses using different measurements of oil price shocks and datasets for countries other than the U.S. Jimenez-Rodriguez and Sanchez (2005) use an econometric vector auto-regression model to address the oil price-macroeconomy relationship within OECD[1] countries. Countries are presumed to react uniquely to oil price fluctuations because of a variety of differences like sector composition and available technology. Using Hamilton's (1996) specification of net oil price increases, the authors find similar non-linear relationships between oil prices and real GDP for all countries except Japan. This result is not robust to changes in lag specification and the authors posit that Japan may be an outlier because of the unique circumstances of its rapidly changing economy. Cunado and de Gracia (2005) have a similar inquiry for Asian countries (Japan, Singapore, South Korea, Malaysia, Thailand and the Philippines). The authors use four different measurements of shocks: all oil price changes, only positive oil price changes, Hamilton's (1996) net oil price increase specification, and scaled oil price increases (introduced by Lee, Ni, & Ratti (1995), focusing on volatility). They find no long-run relationship between oil price changes and macroeconomic activity and conclude that this relationship is confined to the short-run only (for Japan, South Korea, and Thailand). This supports Hamilton's (1983) finding for the U.S. and speaks to the fact that sudden volatility and short-run "stickiness" matters. Linear and long-term price increases give producers and consumers time to adapt.

Hung, Hwang and Peng (2005) contribute to the literature with an analysis of "thresholds" for varying countries' ability to absorb oil price shocks at a macroeconomic level. The authors use a multivariate threshold model to estimate the effects of oil price

[1] The Organization for Economic Cooperation and Development, with 30 member countries.

changes on industrial production and real stock returns for the U.S., Canada and Japan from 1970 to 2002. They define the threshold for an oil price impact to be the percent change in real oil prices beyond which there is an obvious economic impact on production and stock prices. They conclude that past studies have erroneously assumed that any oil price change with a magnitude greater than zero would have linear economic effects after controlling for net oil price increases or decreases. They find that the magnitude of change matters as well as differs for every country. Threshold levels are quite low, ranging from a 2-3% increase in net oil prices. Threshold variation reflects country-specific characteristics such as being a net oil exporter or importer and sector composition.

In general, sudden oil price increases have real negative economic consequences. The timing of the effect and the role of uncertainty makes the relationship somewhat complicated, but the net effect on macroeconomic indicators like real gross state product, inflation, and real wages are undeniable within the literature. These effects are generally confined to the short-run.

2.2. Hawaii and Oil Price Shocks

Gopalakrishnan, Tian, and Tran (1993) studied the impact of oil price shocks on Hawaii's economy from 1974 to 1986 using an econometric vector auto-regression model. Their model looks at the effect of changing oil prices on several national variables (interest rates and real GNP) as well as several local variables (local prices, total civilian labor force, and real personal income). Similar to the larger oil price-macroeconomy literature, Gopalakrishnan et al. (1993) find that initial impacts are more intense and dissipate over time. On a national level, they find that oil price shocks have negative effects on interest rates and real GNP. Locally, oil price shocks are found to have an immediate inflationary effect, although this effect lessens considerably over time. Real personal income similarly decreases rapidly and then normalizes. An interesting and somewhat counter-intuitive finding is that oil price shocks increase employment, at least initially. Gopalakrishnan et al. (1993) explain that this result "lies in factor substitution occurring in different sectors of Hawaii's economy, leading to the replacement of energy-intensive practices by labor-intensive ones" (Gopalakrishnan et al., 1993, 304). The shift of Hawaii's economy away from agriculture and towards service-related industries may change this result with an updated dataset. Hawaii's geographically remote nature and tourism dependent economy make service-sectors highly (indirectly) oil-dependent and unlikely to substitute energy with labor.

3.0 Data Sources

To assess the economic effects on Hawaii's economy of increasing oil prices over time, a number of inputs to the CGE models of the State economy were required. The main dataset used to calibrate the model is based on the DBEDT 1997 Hawaii State

Input-Output (I-O) Study.[2] The State of Hawaii I-O Table has been updated to reflect information from the 2000 Census and shows detail for 131 sectors, three factor markets, and 11 agents of final demand. Because Hawaii is geographically remote, data on imports and exports as well as visitor demand in Hawaii are more tractable than for states in the continental U.S. From the baseline dataset, a Social Accounting Matrix (SAM) is assembled. This is a table that describes the flow of goods, services, and factors through an economy such that the value of what is consumed and exported balances the value of what is produced and imported. The purchases of intermediate inputs and primary factors (labor and capital) are provided for each of the 131 production sectors. Demand for each sector is a combination of intermediate and final demand by households, visitors, government, and exporters. Summary data are given in Tables 1 and 2, and are presented graphically in Figures 4 and 5.

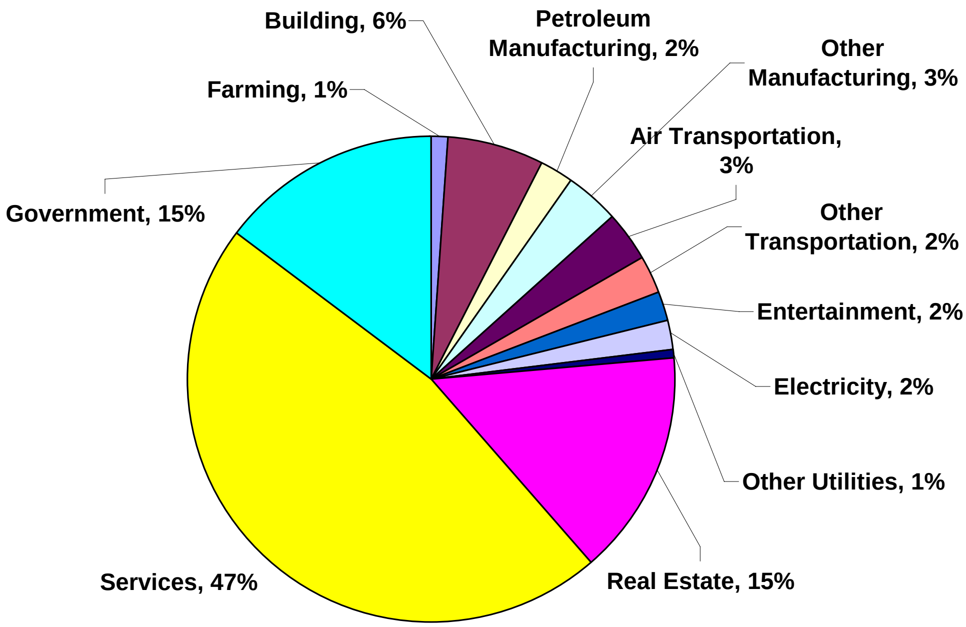
Table 1. Structure of Output and Production in Hawaii

	Output	Inter-industry demand	Imports	Labor income	Proprietor income	Other value added	Jobs
Total	$58.7 bil	$14.4 bil	$5.7 bil	$21.6 bil	$2.1 bil	$14.9 bil	742,231
Farming	1.2%	2.3%	1.3%	1.0%	1.3%	0.9%	2.2%
Building	6.3%	3.4%	11.3%	6.1%	12.1%	1.9%	5.1%
Petroleum Manufacturing	2.4%	5.8%	19.9%	0.2%	0.0%	0.8%	0.1%
Other Manufacturing	3.4%	4.9%	8.9%	2.1%	2.2%	1.6%	2.3%
Air Transportation	3.5%	0.7%	5.3%	2.4%	0.3%	3.5%	1.4%
Other Transportation	2.5%	2.5%	4.0%	1.7%	1.2%	1.3%	1.9%
Entertainment	1.8%	0.4%	2.1%	1.8%	3.0%	1.1%	3.2%
Electricity	2.0%	3.9%	1.9%	0.8%	0.0%	3.0%	0.3%
Other Utilities	0.6%	0.7%	0.4%	0.5%	0.0%	0.8%	0.3%
Real Estate	15.1%	22.2%	2.3%	1.6%	16.9%	41.1%	3.6%
Services	46.7%	49.9%	41.1%	48.4%	63.1%	36.8%	57.5%
Government	14.6%	3.2%	1.4%	33.2%	0.0%	7.4%	22.0%

Source: *The Hawaii Input-Output Study, 1997 Benchmark Report*, Department of Business, Economic Development, and Tourism, State of Hawaii, March 2002.

[2] Although an updated 2002 table exists, this dataset was not used for two reasons. The first is that the 2002 I-O table is much less in-depth (with only 67 sectors) and the specific industries targeted in the analysis, namely petroleum manufacturing and the electric sector, are not entirely represented. Also, in an earlier paper for the 355 Study, it was confirmed that demand for petroleum is much more comprehensively shown within the 1997 I-O table. The second reason is that the September 11th attacks on the World Trade Center greatly affected Hawaii's economy, mainly in its direct impact through tourism industries and thus Hawaii's economy in 2002 is somewhat of an anomaly and not ideal for baseline calibration.

Figure 4. Proportion of Output in Hawaii



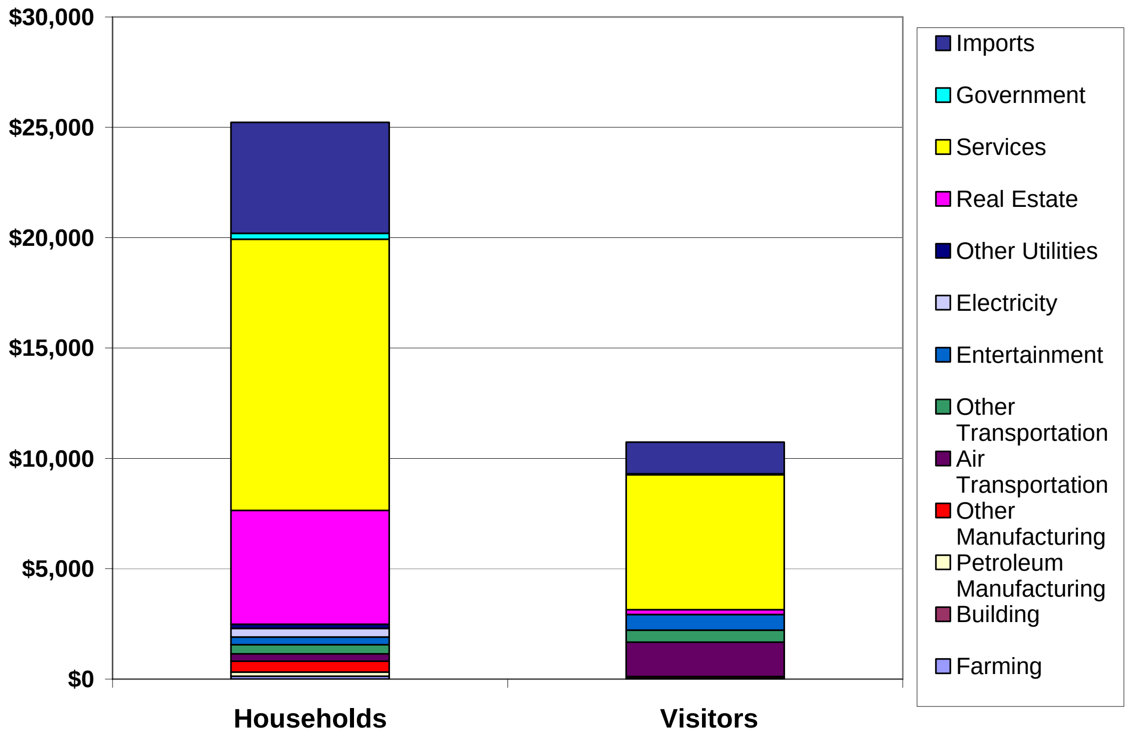
Hawaii's economy is largely service driven, comprising around 47% of total output. For the purposes of this study, "services" are widely defined, including hotel accommodations, restaurant services, and retail trade.

Table 2. Household and Visitor Expenditures in Hawaii

Industry	Hawaii Output ($ million)	Hawaii Output (%)	Household Expenditures ($ million)	Household Expenditures (%)	Visitor Expenditures ($ million)	Visitor Expenditures (%)
Total	72,843	100.0%	25,226	100.0%	10,739	100.0%
Farming	676	0.9%	132	0.5%	18	0.2%
Building	3,672	5.0%	0.0	0.0%	0.0	0.0%
Petroleum Manufacturing	1,419	1.9%	188	0.7%	16	0.2%
Other Manufacturing	1,997	2.7%	495	2.0%	88	0.8%
Air Transportation	2,044	2.8%	338	1.3%	1,555	14.5%
Other Transportation	1,465	2.0%	406	1.6%	536	5.0%
Entertainment	1,074	1.5%	343	1.4%	711	6.6%
Electricity	1,169	1.6%	395	1.6%	0.0	0.0%
Other Utilities	331	0.5%	195	0.8%	0.0	0.0%
Real Estate	8,836	12.1%	5,156	20.4%	218	2.0%
Services	27,404	37.6%	12,286	48.7%	6,113	56.9%
Government	8,566	11.8%	265	1.1%	46	0.4%
Imports	14,189	19.5%	5,028	19.9%	1,438	13.4%

Source: *The Hawaii Input-Output Study, 1997 Benchmark Report*, Department of Business, Economic Development, and Tourism, State of Hawaii, March 2002.

Figure 5. Households versus Visitor Spending



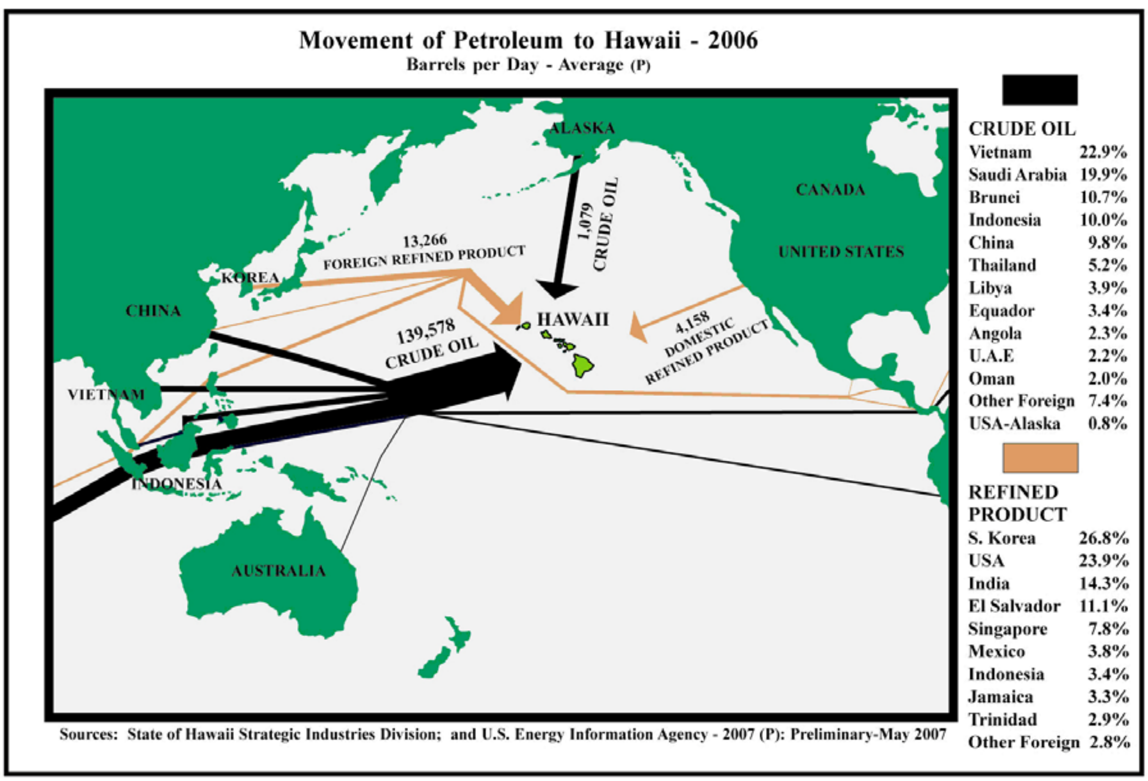
A large portion of services in Hawaii are tourism related. As shown in Figure 5, visitor expenditures generate a significant amount of consumer demand within the State. In addition, residents and visitors purchase a varied mix of goods. For example, residents purchase electricity and other utilities directly while visitors consume these goods only indirectly through service activities (like staying in a hotel). In addition, visitors spend far more on air transportation.

4.0 Static Model and Oil Price Shock Analysis

The models used in this study represent classical Walrasian systems, meaning that goods are produced under perfect competition and constant returns to scale using intermediate commodities, imports, labor and capital. Households supply labor, and final demand is generated by households, visitors, various government entities, and exports. In this portion of the study, Hawaii's economy is modeled as a small open economy operating in the short-run. This implies that nominal wages and the value of capital are fixed, meaning that firms do not have adequate opportunity to renegotiate wages or optimally reinvest in the face of an oil price shock. Given convexity of the production and expenditure sets, equilibrium prices are calibrated to clear markets where supply equals demand. Hawaii producers are modeled as world price takers, including the world price of oil. The model is estimated using the software GAMS (General Algebraic Modeling System) and MPSGE (Mathematical Programming System for General Equilibrium). For more detail on model structure, see Appendix I. The oil price shock is treated as an outside agent consuming a "tax" on the imported inputs into the petroleum manufacturing industry, driving a wedge between current (base) petroleum import prices and new petroleum import prices. Because an outside agent consumes the "tax revenue," the revenue does not generate welfare for any agent within the economy and is thus synonymous with a world price increase. The shock scenarios analyzed are: 1) 10%, 2) 50%, 3) 100% and 4) 200%. The 10% scenario demonstrates how small price changes can matter. The 50% and 100% scenarios are run because this magnitude of change has recently occurred. The 200% scenario replicates a shock proportional to jumping from 1997 oil prices (normalized to 1) to 1975 oil prices (nearly a tripling in world oil prices). The oil price shock is the only source of fluctuation creating the new equilibrium.

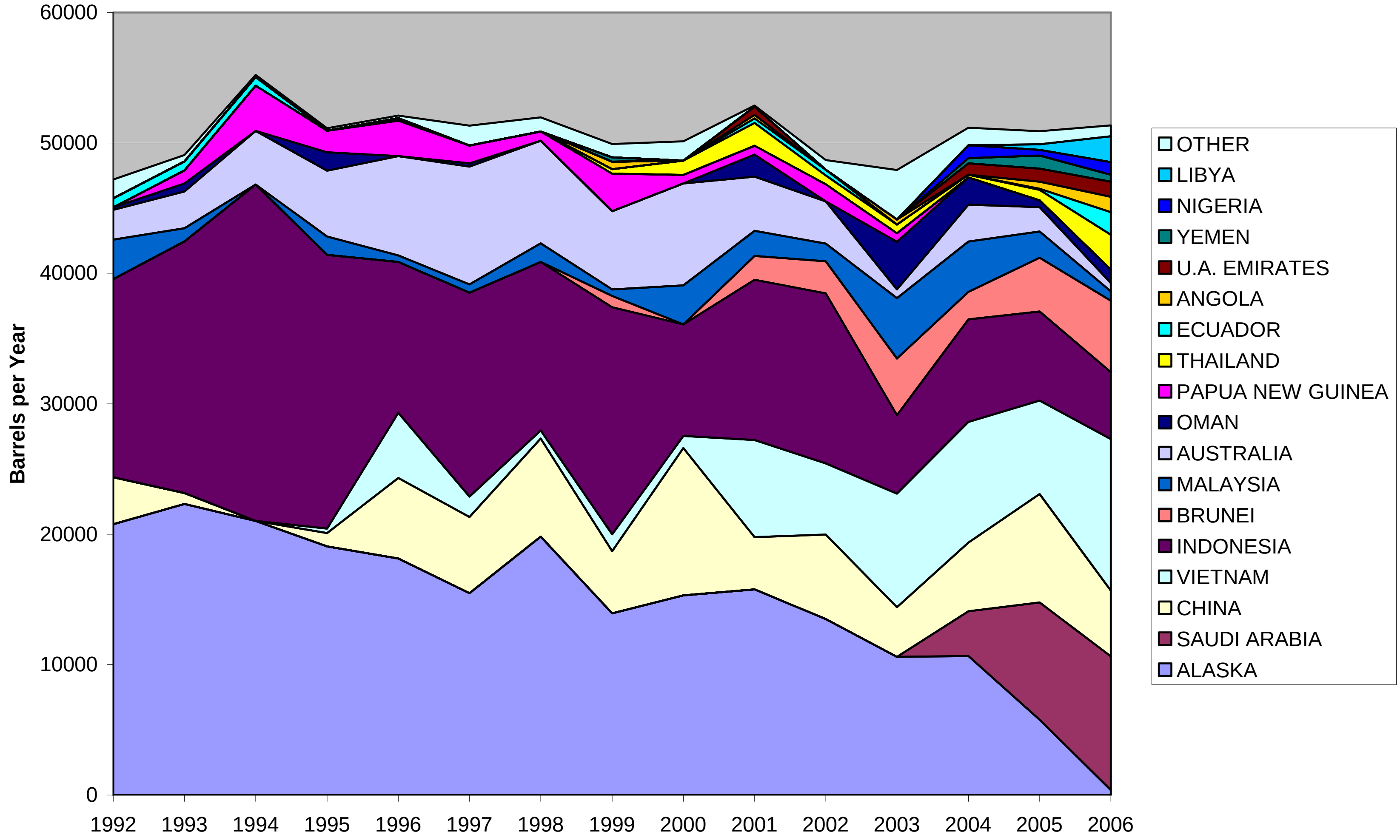
This modeling technique makes two simplifying assumptions. First, it assumes all imports into petroleum manufacturing are crude oil, which is mostly but not entirely the case. This assumption is made because of the proprietary nature of petroleum manufacturing activities as well as the poor data on imports provided within the State of Hawaii I-O table preclude knowing the true proportion and composition of imports into petroleum manufacturing.[3] Second, it assumes all oil products coming into Hawaii are directed through the petroleum manufacturing industry (versus refined product moving directly to other industries). It is reasonable to assume that most oil coming into Hawaii must go through the petroleum manufacturing industry because about 85% of all oil coming into Hawaii is in the form of crude oil. Most of the finished product coming into Hawaii is jet fuel. For detail about the type of oil product coming into Hawaii and place of origin, see Figure 6. Figure 7 shows the history of crude oil sources in Hawaii.

Figure 6. Crude Oil and Refined Product Imports to Hawaii



[3] In the 1997 State of Hawaii Input-Output table, imports are represented through a vector, or composite good into each industry, and do not specify what types of goods make up the total value of imports (i.e., there is no available import matrix typically desirable for a full Social Accounting Matrix).

Figure 7. Hawaii's Crude Oil Sources 1992-2006



Sources: State of Hawaii Strategic Industries Division and U.S. Energy Information Agency, 2007

4.1 Oil Price Shock Macroeconomic Results

The simulation results support the larger oil price-macroeconomy relationship developed within the literature and are presented in Table 3.

Table 3. Macroeconomic Indicators

	Base	10%	50%	100%	200%
	Level	% Change			
Gross State Product ($ million)	$38,616	-0.3%	-1.4%	-2.4%	-4.2%
Real Gross State Product ($constant mil.)	$38,616	-0.5%	-2.1%	-3.7%	-6.3%
Hawaii Consumer Price Index (1997 = 100)	100	0.2%	0.7%	1.3%	2.3%
Hawaii Visitor Price Index (1997 = 100)	100	0.5%	2.1%	3.8%	6.6%
Household Expenditures ($ million)	$24,962	-0.3%	-1.4%	-2.5%	-4.3%
Real Average Household Expenditures ($constant thousand)	$42	-0.5%	-2.0%	-3.6%	-6.1%
Real Average Employee Compensation ($constant thousand)	$35	-0.2%	-0.7%	-1.3%	-2.2%
Labor Force (thousands)	616	-0.3%	-1.2%	-2.2%	-3.9%
Real Visitor Expenditures ($ constant million)	$10,931	-0.4%	-1.9%	-3.3%	-5.7%
Total Output ($ million)	$58,733	-0.1%	-0.4%	-0.6%	-1.0%
Real Total Output ($ constant million)	$58,733	-0.3%	-1.2%	-1.9%	-3.2%

Supporting previous evidence of the oil price-macroeconomy relationship, increasing oil prices are bad for aggregate productivity. Real total output and gross state product decline with increased magnitudes of the shock. In this case the "real" value means 1997 prices held constant and thus changes in output can be thought of in quantity terms (as the price variable drops out). In addition, this analysis replicates the findings of Keane and Prasad (1996) that reduced real wages are coupled with reduced output (contrary to partial equilibrium producer theory that industry output and real wages have a negative relationship). This shows the ability of general equilibrium analysis to explain the conundrum presented by the classical output-wage-oil price relationship. In general equilibrium, a reduced real wage means reduced ability of consumers to demand goods, represented through suppressed real average household expenditures (a proxy for resident welfare), thus supporting reduced industry output. This effect dominates the partial equilibrium effect that reduced real wages also mean the ability to increase sector productivity.

Unlike the finding of Gopalakrishnan et al. (1993), an increase in oil prices leads to increased unemployment within the State. This could be because of the structural changes in the economy since Gopalakrishnan et al.'s study was conducted and also because of the assumption that the shock occurs in the short-run.

The Consumer Price Index (CPI), which represents the composite price of the basket of residential consumer goods (better thought of as the Resident Price Index), is less inflationary than the Visitor Price Index. This shows how visitor consumption patterns are more oil-intensive than resident consumption patterns, particularly in the consumption of air travel.

There is an overall inflationary effect shown through the CPI, supporting the econometric literature. There are, however, competing deflationary effects caused by an increase in world oil prices. The primary and dominant effect is inflationary, occurring from an exogenous price increase in a factor of production. A competing deflationary effect is that an increase in world oil prices leads to a reduction in real visitor expenditures. Visitor expenditures have an inflationary effect within an economy because they act as an exogenous infusion of dollars within the State. Increased oil prices mean that traveling to and visiting Hawaii becomes more expensive in real terms (as represented by a rising Visitor Price Index (VPI)) and visitors purchase relatively less (as represented by decreasing real visitor expenditures).[4] While this has other welfare impacts, particularly on industry demand, it also has this deflationary aspect. The second competing effect, stems from consumers (residents and visitors) shifting demand away from petroleum-intensive sectors (see Table 7 and 8). Resident welfare, as represented through real average household expenditures, decreases under all scenarios. This means that the inflationary effect dominates throughout. This finding suggests the presence of a "threshold," as defined by Hung et al. (2005), although the threshold level is probably quite low and better identified through econometric techniques.

4.2 Sector Level Results

Table 4 shows output levels in constant prices for farming, building, petroleum manufacturing, other manufacturing, air transportation, other transportation, entertainment, real estate & rentals, electricity, other utilities, services and government in the "Base" case as well as the "% change from the Base" case for each oil price shock scenario.

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[4] The static model presented does not consider global effects. In reality, an increase in world oil prices would affect nominal visitor expenditures. This would have an even larger impact on real visitor expenditures than presented above. A simulation that assumes decreased nominal visitor expenditures in Hawaii under each oil price scenario was run, where larger oil price shocks meant less nominal visitor expenditures. The results reinforce the premise that visitor expenditures are inflationary within Hawaii's economy and decreased nominal visitor expenditures similarly have deflationary effects, which would further decrease Hawaii's CPI. There are, of course, other negative effects on Hawaii's economy, particularly debilitating to visitor-related sectors.

Table 4. Real Output by Sector ($ constant million)

Industry	Base $ constant million	10%	50%	100%	200%
		% Change			
Farming	$676	-1.3%	-5.8%	-10.1%	-16.5%
Building	$3,672	-0.1%	-0.3%	-0.6%	-1.1%
Petroleum Manufacturing	$1,419	-7.3%	-23.9%	-34.8%	-47.0%
Other Manufacturing	$1,997	-0.6%	-2.5%	-4.6%	-7.8%
Air Transportation	$2,044	-1.2%	-5.1%	-9.2%	-15.5%
Transportation	$1,544	-0.5%	-2.2%	-3.9%	-6.7%
Entertainment	$1,074	-0.3%	-1.4%	-2.7%	-4.7%
Real Estate/Rentals	$8,836	-0.2%	-1.0%	-1.9%	-3.3%
Electricity	$1,169	-1.7%	-7.3%	-12.7%	-20.7%
Other Utilities	$331	-0.5%	-2.3%	-4.1%	-7.1%
Services	$27,404	-0.2%	-1.0%	-1.8%	-3.1%

As expected, an increase in the world price of oil has the largest affect on the petroleum manufacturing industry (the sector which directly absorbs the shock within the model).[5] Petroleum manufacturing is an intermediate input into other petroleum-intensive industries, causing considerable indirect decreases in the real value of electricity and air transportation. Other particularly affected industries include farming, other transportation, and utilities. Farming is particularly adversely affected because of its labor and oil-intensive nature. Petroleum manufacturing is one of the largest intermediate inputs of the farming sector. The short-run assumption that nominal wages remain fixed means that the farming sector is adversely hit from its large labor input as well (opposed to reducing wages to offset high oil prices).

Services are found to be much more insolated from oil price shocks than manufacturing. The manufacturing sector declines by nearly 8% in the 200% shock scenario while services declines around 3%.

Table 5 shows similar results as Table 4 but in nominal terms (meaning that level values in Table 4 are in constant prices and Table 5 in current prices).

[5] The Hawaii CGE model assumes homogeneous products within sectors. This means it does not consider the impact of differentiated products within the petroleum manufacturing industry. For example, the petroleum manufacturing sector sells jet fuel to the airline industry, gasoline to the transportation industry, and residual fuel oil to the electric sector. The production function of petroleum manufacturing in reality does not smoothly transition from serving the air transportation market to the electricity market but is rather constrained by differentiated products where residual fuel oil is a byproduct of jet fuel production.

Table 5. Nominal Output by Sector ($ million)

Industry	Base $ million	10% % Change	50%	100%	200%
Farming	$676	-1.0%	-4.4%	-7.7%	-12.4%
Building	$3,672	0.0%	-0.2%	-0.3%	-0.6%
Petroleum Manufacturing	$1,419	0.5%	8.3%	20.1%	41.5%
Other Manufacturing	$1,997	-0.5%	-2.0%	-3.5%	-6.0%
Air Transportation	$2,044	0.0%	-0.1%	-0.2%	-0.2%
Transportation	$1,544	-0.2%	-0.6%	-1.0%	-1.7%
Entertainment	$1,074	-0.1%	-0.3%	-0.6%	-1.1%
Real Estate/Rentals	$8,836	-0.2%	-1.0%	-1.8%	-3.1%
Electricity	$1,169	0.9%	4.3%	8.2%	15.3%
Other Utilities	$331	0.0%	0.0%	0.1%	0.3%
Services	$27,404	-0.2%	-0.7%	-1.3%	-2.2%

While the petroleum manufacturing sector is significantly reduced in output in real terms (reduced by 47% in the 200% scenario), it also increases output significantly in nominal terms (increased by 41% in the 200% scenario). This means that the value effect from a change in price dominates the quantity effect. The reason for this is that there are not any import substitutes within the current technological structure of the economy for petroleum manufacturing. Farming output, for example, has a large range of substitution possibilities through imports. Thus the farming sector is adversely impacted from an increase in oil prices in both real and nominal terms. The positive value effect found for the petroleum manufacturing sector is similar for electricity and air transportation. The air transportation sector still experiences a net loss in nominal terms, but it is quite small in comparison to its loss in real terms.

Table 6 shows Real Labor Payments by Sector.

Table 6. Real Labor Payments by Sector ($ constant million)

Industry	Base $ constant million	10%	50%	100%	200%
		% Change			
Farming	$214	-1.4%	-5.9%	-10.2%	-16.7%
Building	$1,320	-0.1%	-0.5%	-0.9%	-1.7%
Petroleum Manufacturing	$52	-7.3%	-23.4%	-34.2%	-46.4%
Other Manufacturing	$465	-0.6%	-2.5%	-4.4%	-7.5%
Air Transportation	$527	-1.2%	-5.2%	-9.2%	-15.5%
Transportation	$371	-0.5%	-2.2%	-3.9%	-6.7%
Entertainment	$393	-0.4%	-1.6%	-2.9%	-5.1%
Real Estate/Rentals	$346	-0.3%	-1.1%	-2.0%	-3.5%
Electricity	$176	-1.7%	-7.3%	-12.7%	-20.7%
Other Utilities	$117	-0.6%	-2.5%	-4.5%	-7.7%
Services	$10,471	-0.3%	-1.1%	-2.0%	-3.6%

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Oil price shocks have negative effects on real wages. This demonstrates general equilibrium's strength in showing the relationship between not just producers but also consumer interactions in determining economic indicators and levels. Although workers are made worse-off in all sectors, it is particularly notable in petroleum manufacturing, affecting an estimated 622 employees

Table 7 shows shifts in consumer demand by sector as a result of the oil price shocks.

Table 7. Real Household Demand by Sector ($ constant million)

Industry	Base $ constant million	10%	50%	100%	200%
		% Change			
Farming	$122	-0.7%	-3.2%	-5.7%	-9.8%
Building	$0	0.0%	0.0%	0.0%	0.0%
Petroleum Manufacturing	$188	-8.4%	-30.9%	-47.1%	-64.1%
Other Manufacturing	$495	-0.5%	-2.2%	-4.1%	-7.1%
Air Transportation	$338	-1.4%	-6.3%	-11.2%	-18.9%
Transportation	$406	-0.6%	-2.8%	-5.1%	-8.9%
Entertainment	$296	-0.5%	-2.4%	-4.3%	-7.6%
Real Estate/Rentals	$5,156	-0.3%	-1.3%	-2.4%	-4.3%
Electricity	$395	-2.9%	-12.2%	-21.2%	-34.0%
Other Utilities	$195	-0.6%	-2.6%	-4.7%	-8.1%
Services	$12,078	-0.3%	-1.5%	-2.7%	-4.9%

Due to overall welfare effects that make households less able to consume a basket of goods (because of inflation and reduced real wages); households reduce their demand over all sectors (with the exception of "building," where there is no direct household consumption). The industries most affected are petroleum manufacturing and electricity. The shift away from petroleum-intensive industries is relatively large. There is a 6% decline in aggregate real household demand, where the real demand of petroleum manufacturing declines by 64%. While it is most easily described as consumers "substituting" away from petroleum-intensive products, this is not a realistic interpretation of the model. In reality, consumers find ways of "conserving" in petroleum-intensive sectors, for example, by turning off the lights and air conditioning to reduce the electric bill and by modifying travel by car and air. In a longer time-frame, consumer substitution effects would include larger investments like buying a more fuel-efficient car and installing solar panels on home roofs.

Table 8 shows the shift in real visitor demand due to a change in oil prices. Visitors similarly reduce demand in petroleum manufacturing and air transportation. There is no direct visitor consumption of building, electricity, and utilities. Visitors increase spending in real estate/rentals and government. This finding is driven by the assumption that aggregate nominal visitor expenditures remain constant because it is exogenously given within the dataset. In reality, nominal visitor expenditures would probably decline in the face of world oil price increases and this would have additional negative impacts to Hawaii's economy.

Table 8. Real Visitor Demand by Sector ($ constant million)

Industry	Base $ constant million	10%	50%	100%	200%
		% Change			
Farming	$18	-0.4%	-1.7%	-3.1%	-5.4%
Building	$0	0.0%	0.0%	0.0%	0.0%
Petroleum Manufacturing	$208	-8.1%	-29.9%	-45.7%	-62.4%
Other Manufacturing	$88	-0.2%	-0.7%	-1.3%	-2.3%
Air Transportation	$1,555	-1.1%	-4.9%	-8.8%	-15.0%
Transportation	$536	-0.4%	-1.6%	-2.9%	-5.0%
Entertainment	$711	-0.2%	-1.0%	-1.8%	-3.3%
Real Estate/Rentals	$218	0.0%	0.1%	0.2%	0.3%
Electricity	$0	0.0%	0.0%	0.0%	0.0%
Other Utilities	$0	0.0%	0.0%	0.0%	0.0%
Services	$6,113	-0.1%	-0.4%	-0.7%	-1.3%

5.0 Analysis of Energy Information Administration (EIA) Oil Price Scenarios

The dynamic Hawaii CGE model takes a long-run view of Hawaii's economy where capital is flexible and labor is fully employed. The model is calibrated to the baseline 1997 dataset and projects economic activity to the year 2025 using both historic data and Hawaii specific forecasts. The University of Hawaii Economic Research Organization (UHERO) uses a long-range forecasting model maintained by Dr. Carl

Bonham to predict population and visitor arrivals growth, construction project growth, and federal civilian and military employment through the year 2025. These projections are modified based on the changing macroeconomic assumptions used by the EIA to determine low, base and high oil price forecasts. Incorporating the UHERO projections into the dynamic CGE model gives the model a global-feedback mechanism. For example, high oil prices drives up the total cost of vacationing in Hawaii, resulting in fewer visitors from both the continental U.S. and Japan. Thus there is a different projection for visitor arrivals incorporated into the model under high oil prices than low oil prices, although the magnitude of difference is rather small. (See Table 9 for population and visitor arrival projections. See Table 10 for EIA oil price projections.) Other variables used to propel the model to the year 2025 include federal expenditure growth and construction projects within the State.

Table 9. Projected Population and Visitor Growth (1997 = 1)

Year	Population *Oil Price Scenario*			Visitors *Oil Price Scenario*		
	Low	Base	High	Low	Base	High
2006	1.08	1.08	1.08	1.10	1.10	1.10
2010	1.13	1.13	1.13	1.20	1.20	1.19
2015	1.20	1.20	1.19	1.29	1.28	1.27
2020	1.25	1.25	1.25	1.38	1.38	1.37
2025	1.31	1.31	1.31	1.46	1.45	1.45

Table 10. EIA Oil Price Projections ($/bbl)

Year	Low	Base	High
2006	67.18	67.18	67.18
2010	64.61	72.78	87.66
2015	50.52	70.98	107.16
2020	48.77	74.23	118.89
2025	48.77	79.18	126.20

Source: EIA Annual Energy Outlook 2006.

The dynamic CGE model is calibrated to the 1997 benchmark and projects to the year 2025 using information from these tables under low, base, and high oil price scenarios (incorporated into the model in a similar manner to the oil price shock scenarios).

6.0 Analytical Results Utilizing EIA Scenarios

The results produced in this section support the findings presented earlier in the oil price shock case. The results of the EIA case are not as pronounced as the static shock case, however, because EIA scenarios predict that, unlike most previous real world occurrences, oil prices rise gradually and linearly. This gives both producers and consumers better ability to respond to rising oil prices, unlike a sudden shock scenario. Specifically, high oil prices have negative effects on both real and nominal gross state product (see Tables 11 and 12).

Table 11. Gross State Product ($ current billion)

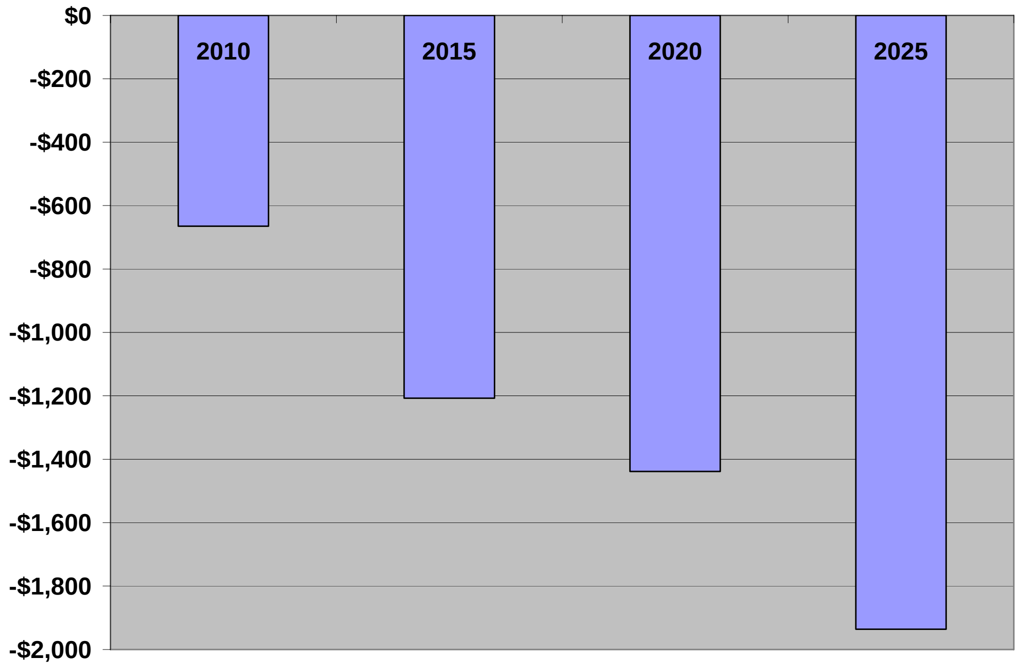
Oil Price Scenario	2006	2010	2015	2020	2025
Low	49.8	61.1	78.2	101.1	133.1
Base	49.8	60.4	76.9	99.8	132.0
High	49.8	59.7	76.0	98.9	130.1

Table 12. Real Gross State Product ($ constant billion)

Oil Price Scenario	2006	2010	2015	2020	2025
Low	44.0	49.4	56.8	65.4	76.0
Base	44.0	49.1	56.2	64.6	75.2
High	44.0	48.7	55.6	63.9	74.1

High oil prices have negative economic effects over time as evidenced by their impact on gross state product, a key indicator of economic health. Real gross state product, in terms of constant dollars, gives a basis for comparison over the time horizon. The aggregate difference between real gross state product under the high and low oil price scenarios over the time horizon for this analysis is nearly $22 billion. The negative economic effects caused by higher oil prices compounds over time, making the difference between high and low oil prices larger over time. See Figure 8 for the difference between real gross state product under the high and low oil price projections.

Figure 8. Difference in Real Gross State Product Between High & Low Oil Price Scenario ($ constant million)



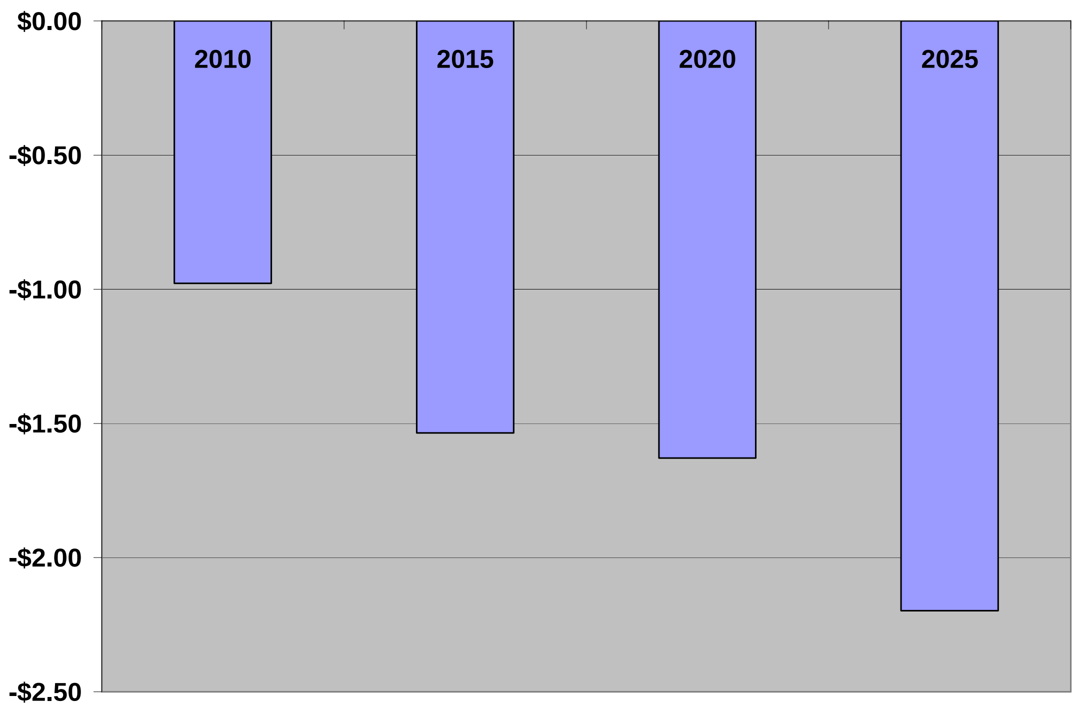
Real average household expenditure is an important parameter for measuring the economic well-being of the State. This is because it infers how much money for both necessary purchases, such as housing and food, and discretionary purchases can be made by a particular household, holding prices (and thus purchasing power) constant over time. To this point, additional discretionary income available to households supports the overall State economy. This information is summarized in Table 13.

Table 13. Real Average Household Expenditures ($ constant thousand)

Oil Price Scenario	2006	2010	2015	2020	2025
Low	48.1	54.3	62.8	73.7	88.4
Base	48.1	53.8	61.9	72.7	87.6
High	48.1	53.3	61.2	72.0	86.2

Real average household expenditures provide a measure of resident welfare. The aggregate difference in real average household expenditure between the high and low oil price scenarios is nearly $27,000 over the entire time horizon. As shown in Figure 9, the largest variance, in the year 2025, is within 2.5% of annual real average household expenditures. While seemingly a small percentage, when multiplied over all of the households in the state, this relatively small yearly percentage can have a significant impact, particularly for lower income households. This small percentage difference should not be minimized. It is beyond the scope of this study to determine impacts of various households, income types, and related purchasing patterns that impact state economic sectors.

Figure 9. Difference in Real Average Household Expenditures Between High & Low Oil Price Scenario ($ constant thousand)



Similar to the findings of the oil price shock simulation results, real output for the petroleum manufacturing industry is *lowest* under the high EIA oil price projection ($1.7 billion in 2025) and highest under the low EIA oil price projection ($2.1 billion in 2025). Nominal output for the petroleum manufacturing industry, however, is *highest* under the high EIA oil price projection ($10.8 billion in 2025) and lowest under the low EIA oil price projection ($6.1 billion in 2025)**.**

7.0 Conclusions

The conclusions are presented separately for the oil price shock analysis and for the longer-term EIA analysis. Some general concluding marks are also incorporated.

It is clear from these analyses that increasing petroleum prices, whether sudden or gradual, will have debilitating effects on the overall State economy. The Hawaii CGE models produce results that support the primary theoretical relationships between oil prices and productivity, wages, and inflation, with important implications for an economy highly dependent on oil and visitor industries. It is outside the scope of the analysis for this report to determine how new non-fossil energy resources or efficiency will penetrate the market in the face of higher petroleum prices and serve to ease the burden placed on Hawaii's economy by higher oil prices.

The analyses of various oil price shock scenarios lead to a number of conclusions:

1) The oil price-macroeconomy relationship developed in this analysis is consistent with econometric literature. That is, sudden oil price shocks decrease real productivity, decrease real wages across sectors, and are inflationary overall. In the 100% increase scenario, a doubling of world oil prices, real gross state product declines by 3.7%, real wages decline by 1.3%, and the Hawaii consumer price index rises by 1.3%.

2) While oil price shocks lead to inflationary pressure within an economy, both consumer demand shifts and the reduction in real visitor spending mean that oil price increases are associated with deflationary effects, suggesting the existence of a "threshold." The inflationary effect nonetheless dominates throughout all examined shock levels, suggesting the threshold level is quite low. The value of the threshold is best identified through the creation of an econometric model.

3) Oil price increases mean a direct reduction in real petroleum manufacturing output (a decline of 34% in the 100% scenario) yet an increase in nominal petroleum manufacturing output (an increase of 20% in the 100% scenario). This shows the value effect of a price increase dominates the quantity effect of consumers substituting away from petroleum products.

4) Increased oil prices indirectly affect the electricity sector through intermediate purchases from the petroleum manufacturing industry. Electricity output declines in real terms (a decline of 13% in the 100% scenario) and increases in nominal terms (an increase of 8%). As with the petroleum manufacturing sector, the value effect of the price increase dominates the quantity effect of consumers substituting away from petroleum products.

5) Output of air transportation declines by 9% in real terms and by 0.2% in nominal terms in the 100% scenario. This has an implicit impact on the tourism industry in the state.

6) The benefit of increased oil prices to the petroleum manufacturing and electric industries (reflected in nominal output increases) suggests these sectors lack market based incentives to switch technologies away from the business of crude oil.[6]

Similar to the findings of Cunada and de Gracia (2005), increasing oil prices have a larger effect in the short-run than the long-run. The static shock analysis shows how oil price volatility has large real economic impacts. In the short-run, even a 10% increase in world oil prices can have negative real economic impacts, for instance a 0.5% decrease in real gross state product and a 0.16% increase in inflation.

[6] This finding, coupled with short-run capital 'stickiness,' supports the conversation and theme of the 2006 Hawaii Economic Association Annual Conference, *"At $65/bbl, Why Not More Change?"*

Analyses of long-run impacts, using the UHERO dynamic model, imply that the economy better adjusts, in comparison to the short-run price shocks, to changing oil prices in the three longer-term EIA scenarios. The 2006 EIA oil price projections were analyzed and results compared under low, base, and high oil price scenarios. Increasing differences in oil prices over time between low and high cases have increasing negative effects on the economy. The largest difference occurs in the final year of analysis, 2025, with over a $2 billion difference in real gross state product between the high and low oil price scenarios. For Hawaii's $70 billion dollar economy (measured in constant dollars as predicted for the year 2025), this is a sizable difference in economic performance due to a change in the price of a single factor of production, oil.

To conclude, it should be noted that there have been no refereed journal articles regarding recent oil price increases and Hawaii's macroeconomic performance. From 2002 to 2006 world oil prices doubled, from $26 to $67/bbl.[7] Regular gasoline prices in Hawaii rose from roughly $1.80/gal to over $3.50/gal.[8] However, Gross State Product has been growing rapidly and unemployment was at a low of 2% in 2006. An updated econometric analysis similar to Gopalakrishnan et al. (1993) could identify the recent relationship between rising oil prices and Hawaii's macroeconomy.

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[7] EIA data used for dynamic Hawaii CGE model.
[8] http://www.hawaiigasprices.com/retail_price_chart.aspx

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Appendix: Model Structure and Assumptions

Hawaii is an excellent case study for CGE modeling because it truly is a small, open economy. Hawaii producers are modeled as world price takers, including the world price of oil. Representing a classic Walrasian system, goods are produced under perfect competition and constant returns to scale using intermediate commodities, imports, labor, and capital. Households supply labor, and final demand is generated by households, visitors, various government entities, and exports. Given convexity of the production and expenditure sets, equilibrium prices are calibrated to clear markets where supply equals demand. The model is estimated using GAMS (General Algebraic Modeling System) and the pre-processor MPSGE (Mathematical Programming System for General Equilibrium).

Production

The production portion of the model consists of a nested Leontief production function where intermediate inputs (including imports) and final factors (capital and labor) determine levels of output. At the first level, a Leontief production function represents final output (Y_j) in sector j = 1,.., n as made up of intermediate inputs (Z_{ij}) of commodity i, and value added (V_j):

$$Y_j = \min[Z_{1j}/\alpha_{1j},...Z_{nj}/\alpha_{nj}, V_j/\alpha_{vj}] \tag{1}$$

where a_{ij}, a_{vj} are unit input coefficients for intermediates and value added respectively.

Intermediate inputs consist of flexible domestically produced and importable commodities represented through an Armington[9] constant elasticity of substitution (CES) production nest:

$$Z_{ij} = [\theta_{Dij} D_{ij}^{(\varepsilon_{ijm}-1)/\varepsilon_{ijm}} + \theta_{Mi} M_i^{(\varepsilon_{ijm}-1)/\varepsilon_{ijm}}]^{\varepsilon_{ijm}/(\varepsilon_{ijm}-1)} \tag{2}$$

where ε_{ijm} is the CES substitution between domestically produced good i and imports by producer j. D_{ij} is sector i demand by producer j for domestically produced goods and M_i is imported demand in sector i. The parameter shares are represented by θ_{Dij} and θ_{Mi}, respectively.

Value added (V_j) consists of capital (K_j), wage labor (L_j), and proprietor income (R_j):

$$V_j = [\alpha_{Lj} L_j^{(\sigma_j-1)/\sigma_j} + \alpha_{Kj} K_j^{(\sigma_j-1)/\sigma_j} + \alpha_{Rj} R_j^{(\sigma_j-1)/\sigma_j}]^{\sigma_j/(\sigma_j-1)} \tag{3}$$

Where σ_j is the CES among value added variables and α_{Lj}, α_{Kj} are the respective parameter shares.

[9] This follows the Armington (1969) assumption that goods are differentiated by country of origin.

The initial endowment of wage labor, proprietor income, and other value added ($\bar{L}_0, \bar{R}_0, \bar{K}_0$) are given within the 1997 baseline dataset and grow at the historic growth rates $\gamma_L, \gamma_R, \lambda_K$ to project the model to the year 2025. The growth projections are used within the dynamic EIA case. The static model remains calibrated to the base year 1997. The proportion of wage labor to proprietor income is assumed to mirror 1997 economic activity while both growing at the rate of resident population growth. Capital accumulation is assumed to grow at a rate mirroring that of construction and mining job growth. All factors are fully employed in equilibrium and are assumed to be fully mobile across sectors. In addition, the following market clearing conditions hold for each factor market, where *L*, *R*, and *K* are aggregate wage labor, proprietor income and other value added:

$$L \equiv \bar{L}_0(1+\gamma_L) = \sum\nolimits_j L_j \tag{4}$$

$$R \equiv \bar{R}_0(1+\gamma_R) = \sum\nolimits_j R_j \tag{5}$$

$$K \equiv \bar{K}_0(1+\gamma_K) = \sum\nolimits_j K_j \tag{6}$$

Output commodity Y_j can either be consumed domestically or exported and, under the Armington assumption, is differentiated for those markets using a constant elasticity of transformation (CET) function between domestic (D_j) sales and exports (X_j).

$$Y_j = [\beta_{Dj} D_j^{(\varepsilon_j - 1)/\varepsilon_j} + \beta_{Xj} X_j^{(\varepsilon_j - 1)/\varepsilon_j}]^{\varepsilon_j/(\varepsilon_j - 1)} \tag{7}$$

where ε_j is the elasticity of transformation and β_{Dj}, β_{Xj} are parameter shares.

It is assumed that producers maximize profits in a competitive market environment, yielding output supply and factor demands for each production sector and factor market in the model.

Consumption

On the demand side, the model reflects the behavior of Hawaii residents (*r*) and visitors (*v*). Both residents and visitors follow a utility-maximizing behavior represented in a Cobb-Douglas function.

$$U_h = \prod\nolimits_i C_{hi}^{b_{hi}} \qquad \sum\nolimits_i b_{hi} = 1 \quad i = 1, \ldots, n \tag{8}$$

where C_{hi} is consumption and b_{hi} the income expenditure share of $i = 1,.., n, m$ (where *n* are the number of domestically produced commodities and *m* is the imported composite good), and consumer type $h = r,v$.

In addition residents and consumers consume both domestically produced goods ($I = 1,\ldots,n$) and an imported composite good (*m*).

$$C_{hi} = [\theta_{Dhi} D_{hi}^{(\varepsilon_{him} - 1)/\varepsilon_{him}} + \theta_{Mh} M_h^{(\varepsilon_{him} - 1)/\varepsilon_{him}}]^{\varepsilon_{him}/(\varepsilon_{him} - 1)} \tag{9}$$

where ε_{him} is the Armington CES between domestically produced good i and imports by consumer h. D_{hi} is sector i demand for domestically produced goods and M_h is imported demand by consumer h.

A representative resident's expenditure constraint can be written as:

$$\sum_i p_i C_{ri} = p_L L + P_R R + P_K K + \overline{p}_{fx} BP - T_r \tag{10}$$

where prices p_i represent the market prices for imports and commodities i = 1,.., n, m respectively. The resident derives income from factors of production including labor (L), proprietor income (R), and capital (K), where p_L, p_R, p_K are the market price of the respective factors. The resident pays a lump-sum tax (T_r), net of transfer payments, to the state and local government (and thus household income is not necessarily equal to labor income because of transfers). The resident also receives foreign exchange ($\overline{p}_{fx} BP$) from a balance of payment deficit, described below in equation (15).

A representative visitor's income is taken to be exogenous income (I_v), represented by:

$$I_v \equiv I_{v0}(1+\lambda_v) = \sum_i p_i C_{vi} \tag{11}$$

where I_{v0} is the initial visitor expenditure and λ_v serves as an exogenous visitor expenditure shock parameter. This parameter is estimated using increased visitor arrivals information. Because detailed visitor expenditures data over time is unavailable, visitor arrivals data is used as a proxy and assumes constant levels of visitor spending. A review of economic activity levels within the State, however, shows that this method closely replicates near-term visitor spending activity.

Government

The SAM represents government activity through three branches: the state and local government (SL), the federal military government (FM), and the federal civilian government (FC). Each government type purchases domestic commodities (G_{gi}) and imports (G_{gm}) according to a Leontief utility function to assure a constant level of public provision, where $g = SL, FM, FC$.

The state and local government depends entirely on the economy for the tax base.

$$\sum_i p_i G_{SLi} + p_m G_{SLm} = \sum_i p_i Y_i \tau_i + T_r \tag{12}$$

A primary source of revenue is the State's goods and services tax (τ_i) on the sales (Y_i) of commodity i. The state and local government also impose a variety of taxes, such as property and income taxes, on residents.

Federal government inflows, both military and civilian, are assumed to adjust endogenously to assure neutral levels of federal government provision (i.e., unaffected by the shock). The federal public sector budget constraints are given by:

$$\sum_i p_i G_{FMi} + p_m G_{FMm} = I_{FM0}(1+\gamma_{FM}) \equiv I_{FM} \tag{13}$$

$$\sum_i p_i G_{FCi} + p_m G_{FCm} = I_{FC0}(1+\gamma_{FC}) \equiv I_{FC} \tag{14}$$

where the sum on the left-hand side represents the cost of public expenditures. The terms I_{FM0}, I_{FC0} represent initial federal revenue inflows and γ_{FM}, γ_{FC} represent exogenous income multipliers for military and civilian agencies (used in the dynamic EIA case).

Balance of Payments

A balance of external payments (BP) is maintained under the assumption of a fixed (to the dollar) exchange rate ($\overline{p}_{fx}$), where $\overline{p}_{fx}$ is the exchange rate with the "rest of the world." The quantity of imports (M) are constrained by the inflow of dollars obtained from visitor expenditures (I_v), federal government expenditures (I_{FM}, I_{FC}), and Hawaii exports (X_j). Because Hawaii is a small open economy and thus a price taker, import and export prices are perfectly inelastic.

$$\overline{p}_{fx} BP = \overline{p}_m M - I_v - I_{FM} - I_{FC} - \sum_j \overline{p}_{xj} X_j \tag{15}$$

Demand Equals Supply

Constant returns to scale and perfect competition ensure that the producer price (p_j) equals the marginal cost of output in each sector j. In addition, the State and Local Government collects a general excise tax (τ_j) on sales. This implies that the value of total output (supply) equals producer costs, where p_L, p_K, p_R, equal the market price of labor, capital, and proprietor income respectively.

$$p_j Y_j (1+\tau_j) = \sum_{l=1,..,n} p_l Z_{lj} + P_L L_j + p_k K_j + p_R R_j + p_m M_{Yj} \tag{16}$$

In addition, sector j output, which supplied to the domestic market (D_j), is demanded by consumers $h \in \{r,v\}$, government agencies $g \in \{SL,FC,FM\}$, and industries j = 1,.., n.

$$D_j = \sum_h C_{hj} + \sum_g G_{gj} + \sum_l Z_{li} \tag{17}$$

In equilibrium, the value of output balances the value of inter-industry, consumer, and government agencies demand.

Static and Dynamic Hawaii CGE Models

The static and dynamic models use similar structures and modeling assumptions. The static model does not require "updating" or "growing" of key variables using UHERO forecast data. The static model is a representation of the short-run and thus nominal wages and capital are held constant before and after oil price shocks. The dynamic model is a long-run representation of Hawaii's economy, meaning capital is flexible and the model represents full-employment.

All models are simplified representations of the world. The Hawaii CGE models described above are "frictionless," meaning there are no transaction costs and price adjustment is instantaneous. The models also assume homogeneous products within sectors. This means that it does not consider the impact of differentiated products within the petroleum manufacturing industry. For example, the petroleum manufacturing sector sells jet fuel to the airline industry, gasoline to the transportation industry, and residual fuel oil to the electric sector. The production function of petroleum manufacturing does not in reality smoothly transition from serving the air transportation market to the electricity market but is rather constrained by differentiated products where residual fuel oil is a byproduct of jet fuel production.